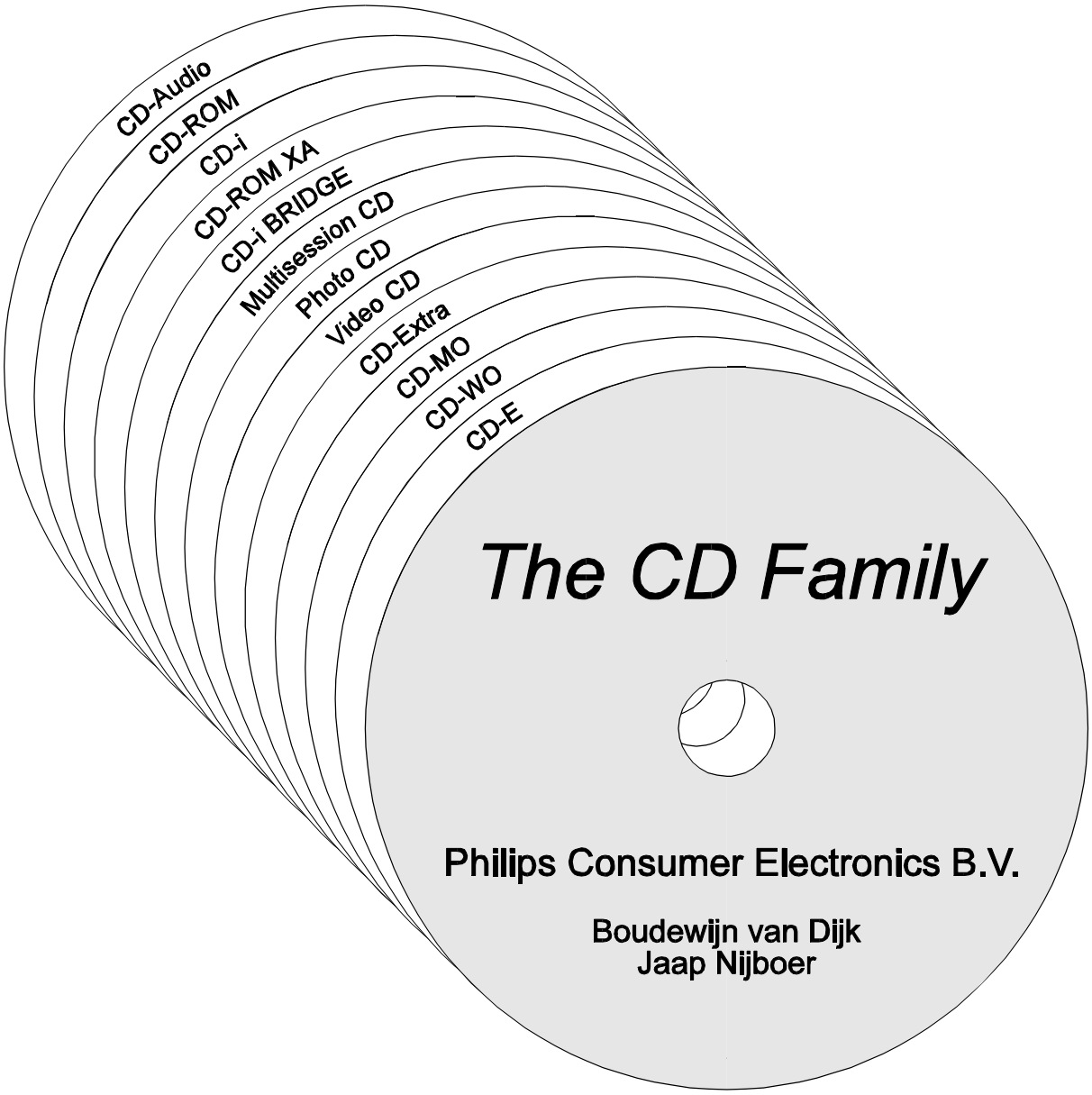

Philips Consumer Electronics B.V.

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An overview of the existing CD formats and their interrelations

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THE CD FAMILY

Logical, compatible and flexible information storage and interchange media

1. THE STORY OF A FAMILY

CD is surely one of the major technological phenomena of our era. Beginning as a pure, high-quality sound reproduction system, it rapidly developed into a whole family of systems, with applications extending across the entire landscape of data storage and distribution.

This family did not arise by accident. Each member is a fully compatible development of its predecessor, and each paves a practical way to succeeding systems.

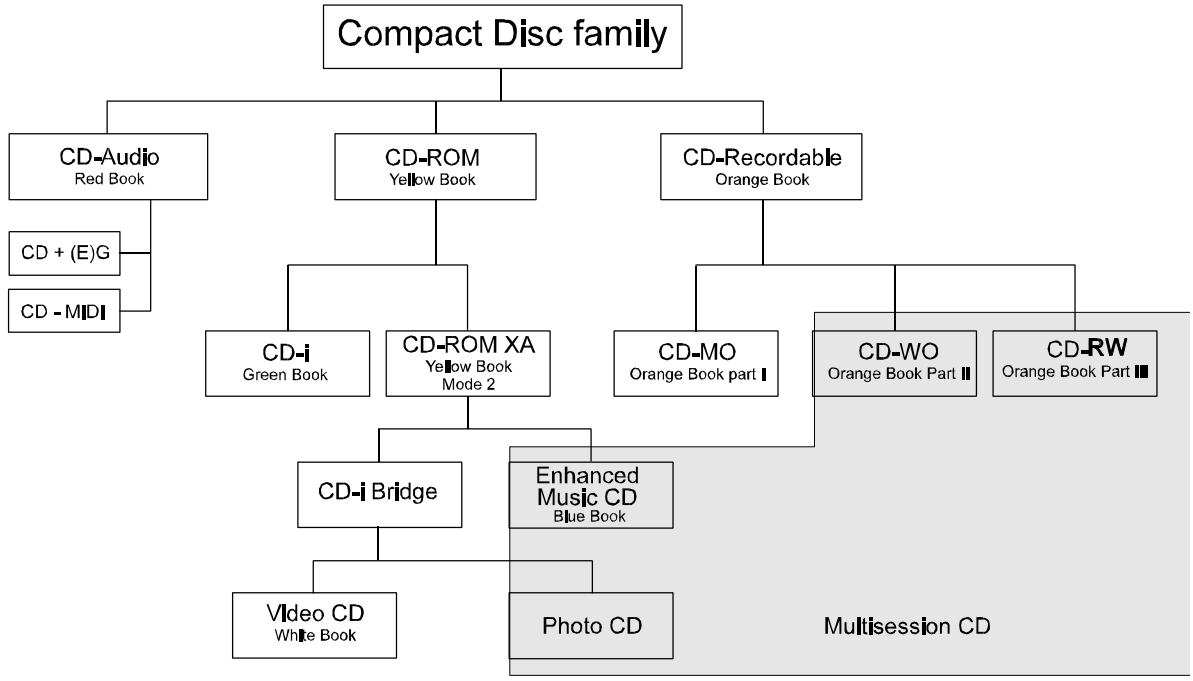

Figure 1: CD family tree

The precursor of CD was LaserVision, the LP-sized optical disc with analogue video and audio. Originating as a linear playback system in 1978, it went interactive in 1981.

By that time, digital optical recording technology was making great strides, leading to the launch of the Compact Disc Digital Audio system (CD-DA) in 1982.

The first data storage and interchange system, CD-ROM, arrived in 1984. It was conceived as a computer peripheral. Three years later, in 1987, the stand-alone, interactive multimedia system CD-i, made its appearance. A link between these two platforms, which in fact gives CD-ROM true multimedia functionality, is CD-ROM XA, born in 1989.

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In 1990 the CD family was taken down a significant new path: recordability. CD-WO (Write Once) allowed users to make their own, non-erasable, optical disc recordings.

To achieve compatibility between CD-i and other playback systems, CD-i Bridge was established in 1991. This paved the way for Photo CD in the same year, Karaoke CD in the year following, and Video CD (embracing Karaoke CD) in 1993. All these are, in fact, applications of CD-i Bridge.

To complete the story to date, CD-i was extended with Full-Motion Video in 1993, while 1995 saw the advent of the Enhanced Music CD (a mixed application of CD-Audio and CD-ROM XA on a Multisession CD) and the erasable Compact Disc, CD-E.

The growth of the CD Family has always been relatively simple and perfectly logical. It had to be for the family to thrive in the way it has. Let us examine how it all happened, and the state of the relationships between the members of the family.

2. HOW THE CD FAMILY CAME TO BE

2.1 Optical Recording

The idea of optical storage was conceived in the late sixties. Among other pioneers were Klaas Compaan and Piet Kramer of the Philips Research Laboratories.

On, or rather in, a pre-recorded optical disc, the recording consists of a spiral track of microscopic depressions (pits) in a highly reflective surface. With a pitch of about 1.6 µm, the track of an optical disc is 60 times denser than the old LP groove. On a standard 120 mm diameter, 1.2 mm thick disc, it can be nearly 6 km long.

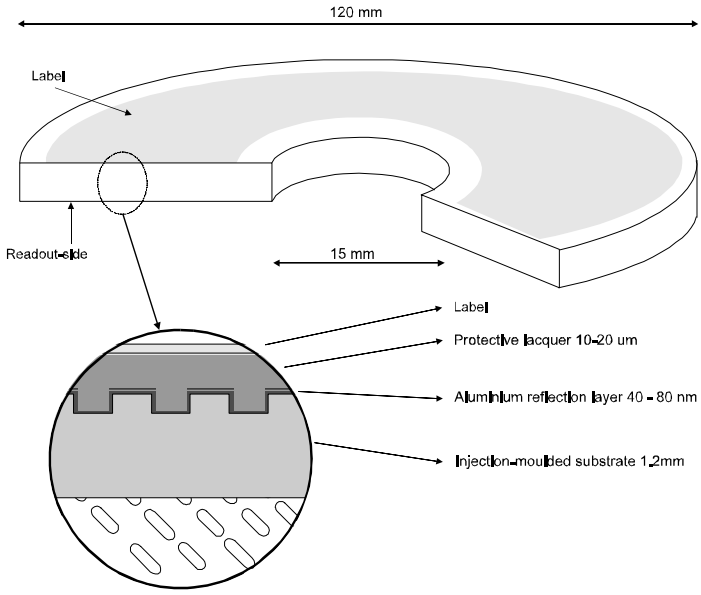

Figure 2: Main structure of a Compact Disc

The reflective surface is of aluminium sputtered on a transparent (polycarbonate) injection moulded disc. Another protective layer is deposited over the aluminium, and this is the surface on which the label is printed.

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The recording is read by a laser beam, focused through the transparent disc onto the reflective layer. By a combination of multipath interference and beam diffraction, the pits attenuate the returning beam. The resulting changes in the intensity of the reflected light, which constitute the recorded data, are detected by a photodiode array.

A very simplified explanation of the beam attenuation is as follows. Multipath interference arises from the fact that the pit depth is about equal to a quarter wavelength of the laser light. Light reflected from the pit bottom is thus out of phase with light reflected from the surface, and the two tend to cancel out (see fig 3). Furthermore, the width of the pit means that it acts as a diffraction slit, with multipath interference (orders) in several directions (see fig 4). This phenomenon reduces the intensity of the zero'th order (Central Aperture) of the reflected beam by a minimum of 60%.

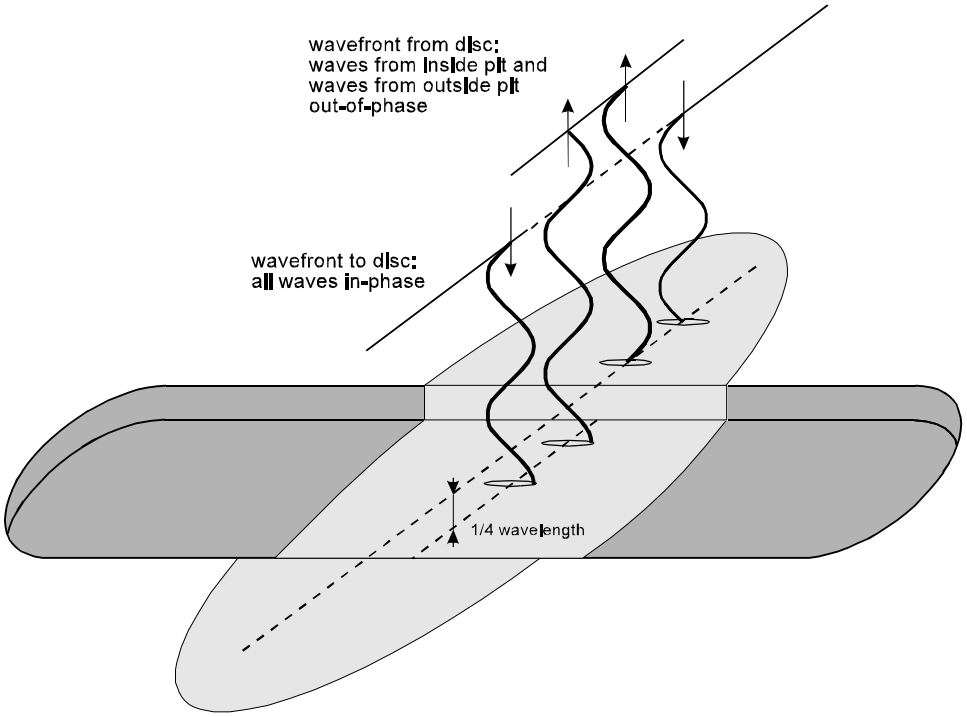

Figure 3: Light extinction due to phase differences

The detectable data density is limited by the maximum spatial resolution of the read-out spot, which is inversely proportional to the laser wavelength, and directly proportional to the numerical aperture (NA) of the focusing lens (NA = n sin α, where n is the refractive index of the substrate and α is the angle between the optical axis and the outer edge of the focussed beam). Compact Disc systems employ an aluminium gallium arsenide (AlGaAs) semiconductor laser at a wavelength of the order of 780 nm. With an NA of around 0.45, the (half-intensity) diameter of the spot is around 0.9 µm, somewhat wider than the 0.6 µm pit width.

An array of two or four photodiodes is necessary because, in addition to the data to be retrieved, differential signals have to be derived to control the tracking and focusing of the laser spot on the information track. The performance of the tracking servo is critical: as a consequence of eccentricity and turntable tolerances, the track can have a side-to-side swing of 300 µm, but the laser must stay within 0.4 µm of the track axis. Likewise, although the disc may rise and fall by as much as 1 mm, the depth of focus at the reflective layer is only about 2 µm.

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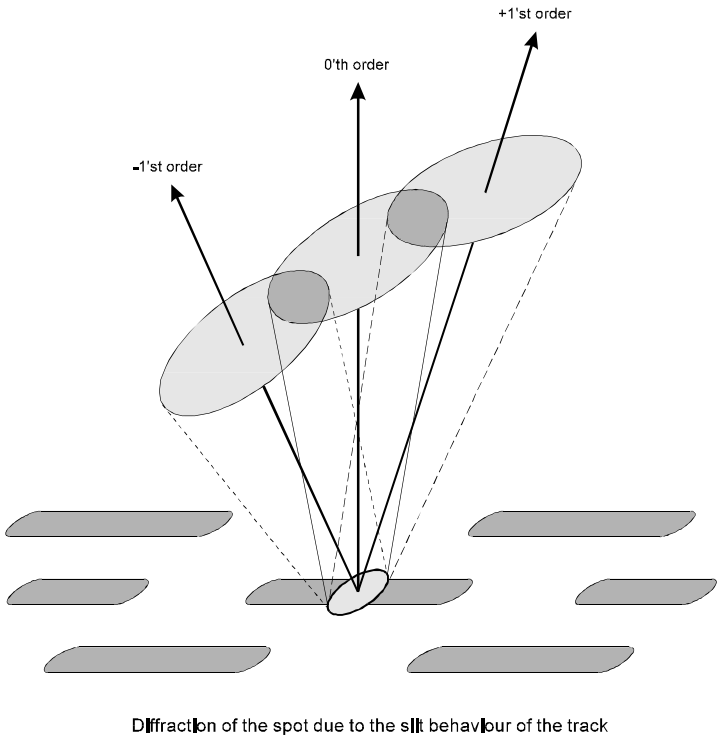

Figure 4: Diffraction of the read-out spot due to slit behaviour of the track

2.2 Audio: CD-DA

By the end of the Seventies, analogue sound reproduction was reaching its limits of performance. The dynamic range of even a new LP could be as low as 60 dB, with a channel separation of only 30 dB. These figures look distinctly disappointing today. Furthermore, the gramophone record had always been liable to wear, deterioration and accidental damage.

Various efforts had already been made to record analogue video and audio on optical discs. They led, in fact to LaserVision.

More importantly, they led to CD-DA.

Optical recordings, buried inside the disc and read by laser beam, did not suffer from wear. They were well protected from damage. And by using digital techniques, several new features became possible:

- The discs could be made to very high audio specifications.
- They could be made very easy and convenient to play, with fast access to individual tracks.
- The discs could be very compact (12 cm diameter for more than an hour's play). Consequently, and significantly, the players could be very compact too.
- Erroneous data could be corrected by means of an error correction system.

Common interests brought Philips and Sony together in working on this project. Following the successful demonstration of a laboratory prototype by Philips in 1979, the Compact Disc Digital Audio System Description was proposed in 1981. This rapidly gained industry acceptance and became a de facto world standard.
Compact Disc Digital Audio quickly caught the attention of consumers and professionals alike.

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A major reason for this was that, in establishing the system as a worldwide standard, Philips and Sony were determined on full support to the licensees, to guarantee compatibility and creat confidence in market development.

The structure of CD-DA

CD is a digital storage and playback medium. As such, it is based on bits, encoded in a specific way. Although designed for audio, it has proved flexible enough to adapt readily to the requirements of other types of information, while still maintaining a compatible data and disc structure.

The original requirement was to convert sound (analogue audio) into a digital format suitable for registration on a disc, in such a fashion that this format could be restored (decoded) to analogue form by a special player. A successor to the gramophone, thus.

Encoding: the bitstream

The first stage of encoding is the generation of a digital bitstream directly representing the sound.

The (time and amplitude continuous) analogue signal is converted into discrete digital samples by sampling and quantization.

To allow for a maximum audio frequency of 20 kHz, a sampling frequency of 44.1 kHz was chosen. This is slightly over twice the required maximum audio frequency, and so satisfies Nyquist's Sampling Theorem.

The sampled amplitude is divided into equal parts by uniform quantization: one word of 16 bits each for both the left and right stereo channels, giving a total of 32 bits (= 4 bytes) per sample - and an inherent S/N ratio in excess of 96 dB. The resulting bit stream is pulse code modulated (PCM), and has a net bit rate of:
$44.1 \times 10^3 \times 32 = 1.41$ Mbits/sec.

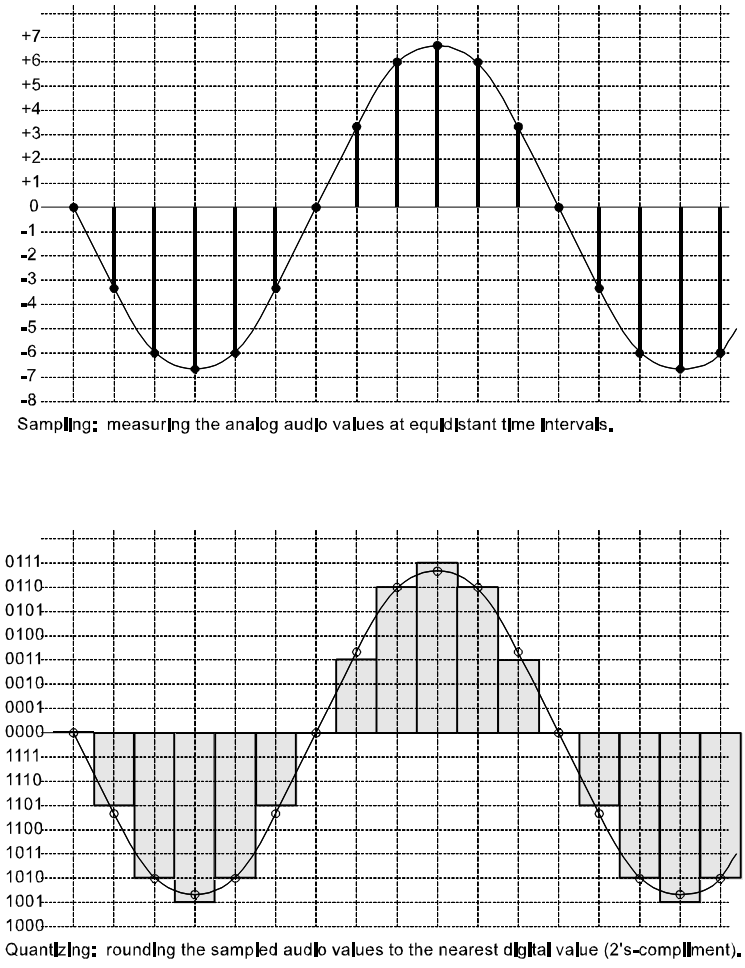

Figure 5: Sampling and Quantization of the Audio signal

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Encoding: Error Detection and Correction

To make it possible to detect and correct errors during playback, parity bytes are added to the bitstream. This calls for a second level of structure to enable the parity pattern to be imposed; an audio frame containing six audio samples (24 bytes) was chosen. The error correction code adopted was the Cross-Interleaved Reed-Solomon Code (CIRC). 8 bytes (4 bytes each of CIRC cross-interleaving components C1 & C2) are added to each audio frame. Cross interleaving has the effect of shuffling the order of the data, which spreads out any burst error into smaller errors, enabling the error correction system to correct these.

Encoding: the Subcode

For playback control and display functions, one more byte is allocated to each audio frame. This is the subcode byte. The Subcode has its own channel, separate from the main (audio) channel, with its own structure and error detection/correction code.

Encoding: Eight-to-Fourteen modulation (EFM)

In storing the CD signal on the disc, the run-length of the modulated channel bit sequences is limited to a minimum of 3 and a maximum of 11 successive bits having the same value ("0" or "1"). This is out of spatial frequency considerations, the requirement for self-clocking of the decoded signal, and a wish to optimize the data density.

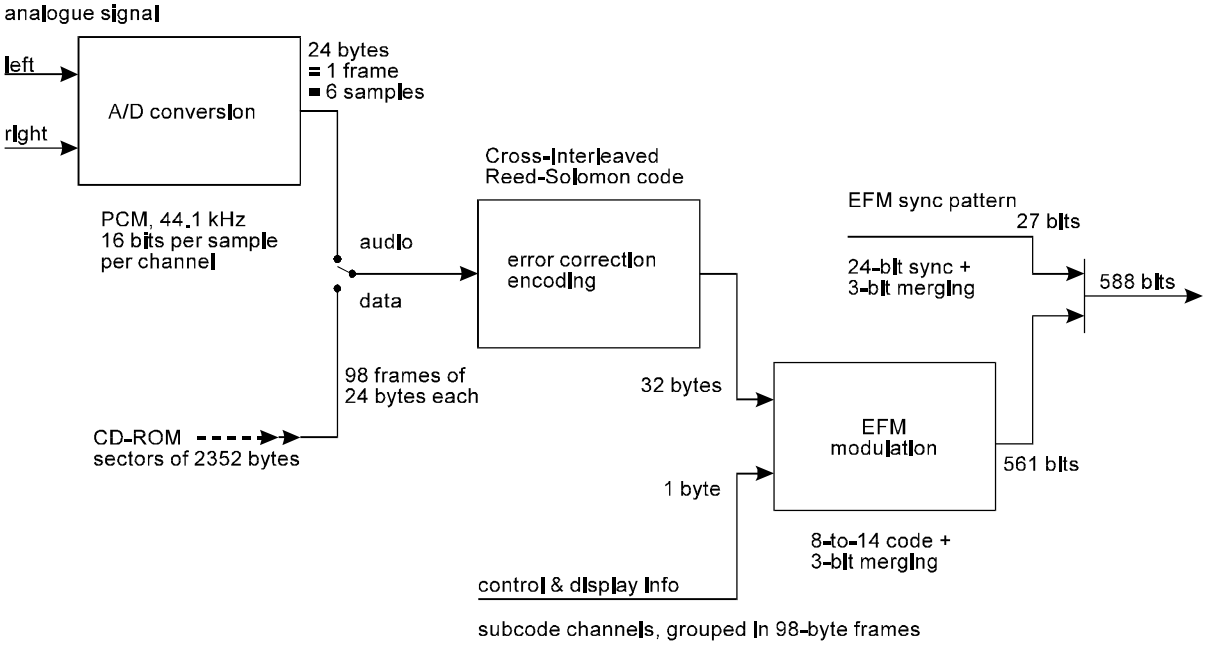

Figure 6: CD-DA Encoding model

To satisfy these conditions, eight-to-fourteen modulation (EFM) is imposed. Each byte (8 bits) of audio, CIRC and subcode data is transposed by a look-up table into 14 channel bits. To ensure that the proper pattern with run-lengths of min 3 and max 11 channel bits is maintained between units, and to suppress noise in the servo-band frequencies (< 20 kHz), 3 merging bits are added to each 14-bit EFM unit. Finally, to allow recognition of individual frames, a sync

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pattern is added to each frame.
In the EFM format, a frame is thus composed of 33 EFM codes of 17 bits each, plus 27 Synchronization bits. This unit of 588 channel bits is known as an EFM frame.

These overheads result in a channel bit rate of 4.32 Mbits/sec. With the CD disc geometry, this allows a theoretical maximum playing time of 79 minutes and 58 seconds.

$$T = \frac{\pi * (R_{end}^2 - R_{start}^2)}{v * p}$$

where T = playing time
R_{end} = end radius of track
R_{start} = start radius of track
v = linear velocity
p = track pitch

To allow for practical limitations and manufacturing tolerances, the maximum playing time is in fact limited to about 74 minutes.

Encoding: the Subcode frame
The 8 bits in a subcode byte each forms part of a separate information channel (Subcode Channels P-W). The P channel marks the lead-in, program and lead-out areas of the disc, and the intervals between tracks. In the lead-in area, the Q channel carries a table of contents (TOC), containing the starting address of each track in the program area, repeated several times. In the program area, the Q channel carries track numbers, times, and in-track indices (see fig 8). In different modes, it also registers the manufacturer's disc catalogue number and ISRC code. All Q-channel data is protected by a Cyclic Redundancy Check against errors.

Channels R-W are allocated for text and graphics purposes, and are used in CD+G and CD-MIDI discs. The data is block structured, and error protection is by Reed-Solomon codes.

One complete cycle of subcode information extends over a block of 98 EFM frames - and is known as a subcode frame. At 24 audio bytes per EFM frame, a subcode frame thus equates to 98 x 24 = 2352 bytes of actual audio data (see fig 7).

The data rate is 75 subcode frames per second, allowing a time code in minutes, seconds, and frames. This is accurate enough to point to the start of a music track. In fact, a big advantage of CD was quickly perceived to be the ease and convenience with which music tracks could be found and played. It is also usefully related to the 25 and 30 frames per second rates of video recordings.

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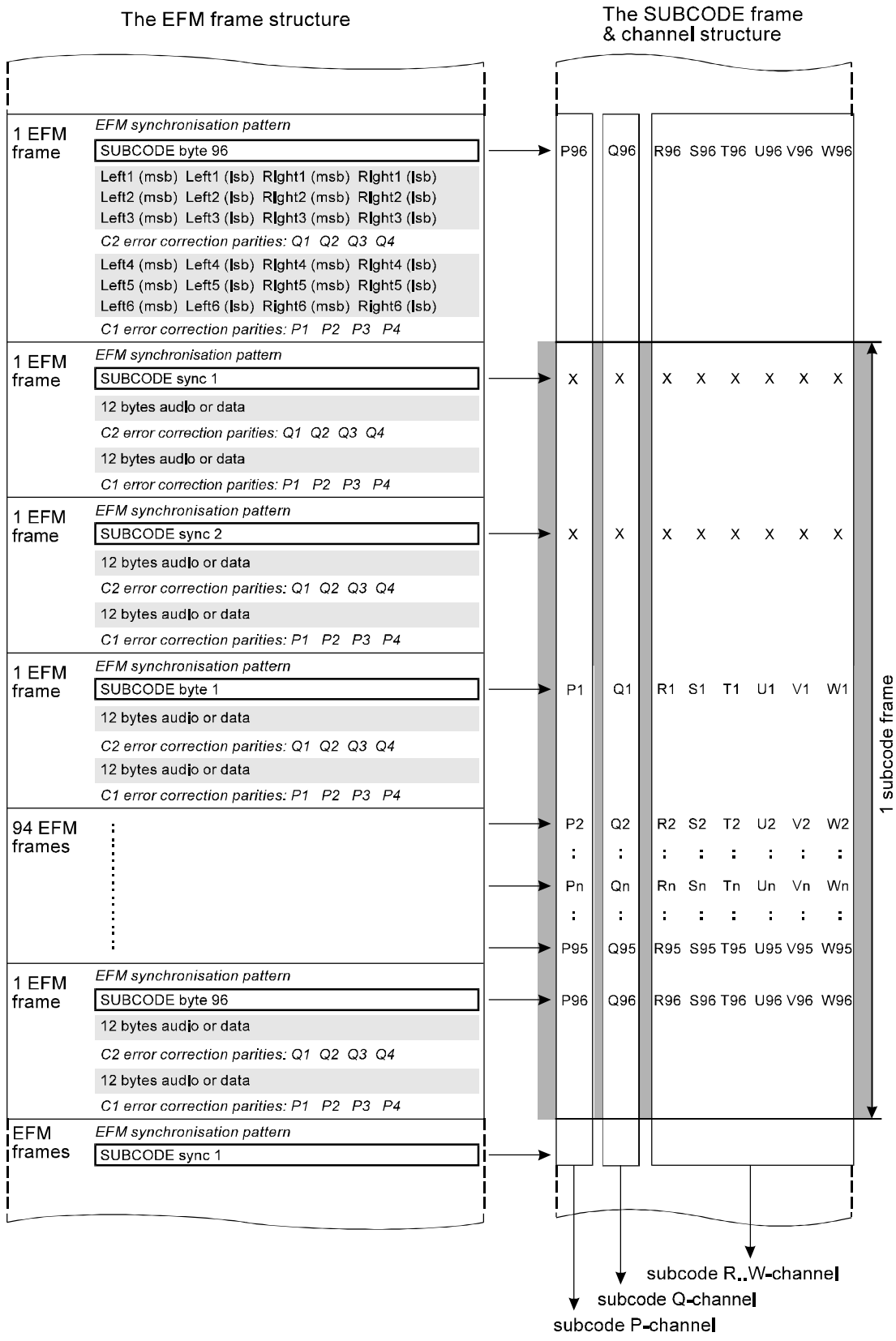
The EFM frame structure
The SUBCODE frame & channel structure
1 EFM frame
EFM synchronisation pattern
SUBCODE byte 96
Left1 (msb) Left1 (lsb) Right1 (msb) Right1 (lsb)
Left2 (msb) Left2 (lsb) Right2 (msb) Right2 (lsb)
Left3 (msb) Left3 (lsb) Right3 (msb) Right3 (lsb)
C2 error correction parities: Q1 Q2 Q3 Q4
Left4 (msb) Left4 (lsb) Right4 (msb) Right4 (lsb)
Left5 (msb) Left5 (lsb) Right5 (msb) Right5 (lsb)
Left6 (msb) Left6 (lsb) Right6 (msb) Right6 (lsb)
C1 error correction parities: P1 P2 P3 P4
SUBCODE sync 1
SUBCODE sync 2
SUBCODE byte 1
12 bytes audio or data
94 EFM frames
EFM frames
P96 Q96 R96 S96 T96 U96 V96 W96
X X X X X X X X
P1 Q1 R1 S1 T1 U1 V1 W1
P2 Q2 R2 S2 T2 U2 V2 W2
Pn Qn Rn Sn Tn Un Vn Wn
P95 Q95 R95 S95 T95 U95 V95 W95
1 subcode frame
subcode R..W-channel
subcode Q-channel
subcode P-channel

Figure 7: EFM and Subcode frame structures

Recording
By means of a laser, the EFM signal is recorded onto a master disc as a continuous spiral track. To achieve maximum data density, the recording is made at a Constant Linear Velocity (CLV). The recording, which begins at the inner radius of the disc, starts with a Lead-in Area containing P and Q-channel Subcode, including the Table of Contents (TOC). Then comes the Programme Area, consisting of up to 99 tracks, followed by the Lead-out Area, both with P and Q-channel Subcode containing time and track information.

From the master, stampers are made for use in the injection moulding process by which the familiar CD is replicated.

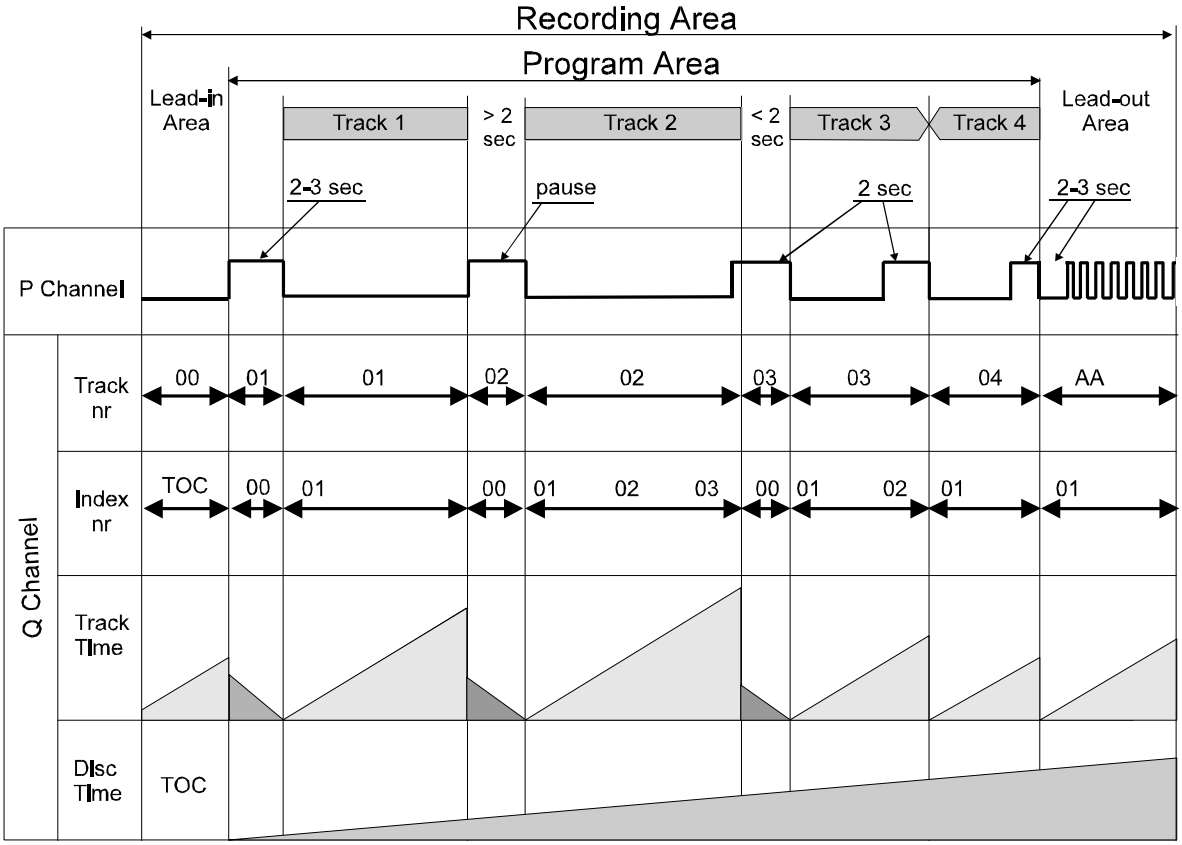

Figure 8: General track layout as given by channels P and Q of the subcode

Playback
In the CD player, the disc again spins at the same constant linear velocity, which means that the turntable motor gradually slows down from about 540 rpm at the beginning, to as low as 200 rpm at the end, depending on the length of the recording.

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Decoding

The encoding format, specified in the CD-DA System Description, or Red Book, enables a CD player to read data from the disc using a laser pick-up, and to derive the EFM signal from it.

For a good audio quality, the main channel data has to arrive at the output of the decoder at a fixed and very constant rate. The EFM data rate however, is variable, because it is directly proportional to any CLV speed variation on the disc (eg. due to eccentricity). The turntable motor control system, with its limited bandwidth, is not able to cancel these variations with sufficient accuracy. The demodulated EFM data is therefore forwarded to a first-in/first-out (fifo) buffer, of which the input is clocked by the EFM bit clock, and the output is clocked by the X-tal system clock. The filling factor of the fifo buffer is used to control the turntable motor speed, and thus the average data input rate from the disc. As the fifo buffer fills up, the motor is slowed down and vice versa. The data that flows into the error correction circuit is thus delayed, but arrives at a fixed (X-tal clock) rate at the output.
The subcode data and its clock signal are extracted directly from the EFM demodulator, which means that the rate varies proportionally to the CLV speed variations.
Due to the variable time delay of the main channel decoding, which depends on the filling factor of the fifo buffer, and the varying data rate at the output of the subcode processor, there is a variable time difference between the arrival of the main channel data, and the arrival of the subcode data, at their respective outputs.
For the access and display functions in CD-Audio these differences are small enough not to be disturbing. For CD-ROM however, as will be seen later, special requirements are needed to improve the access accuracy.

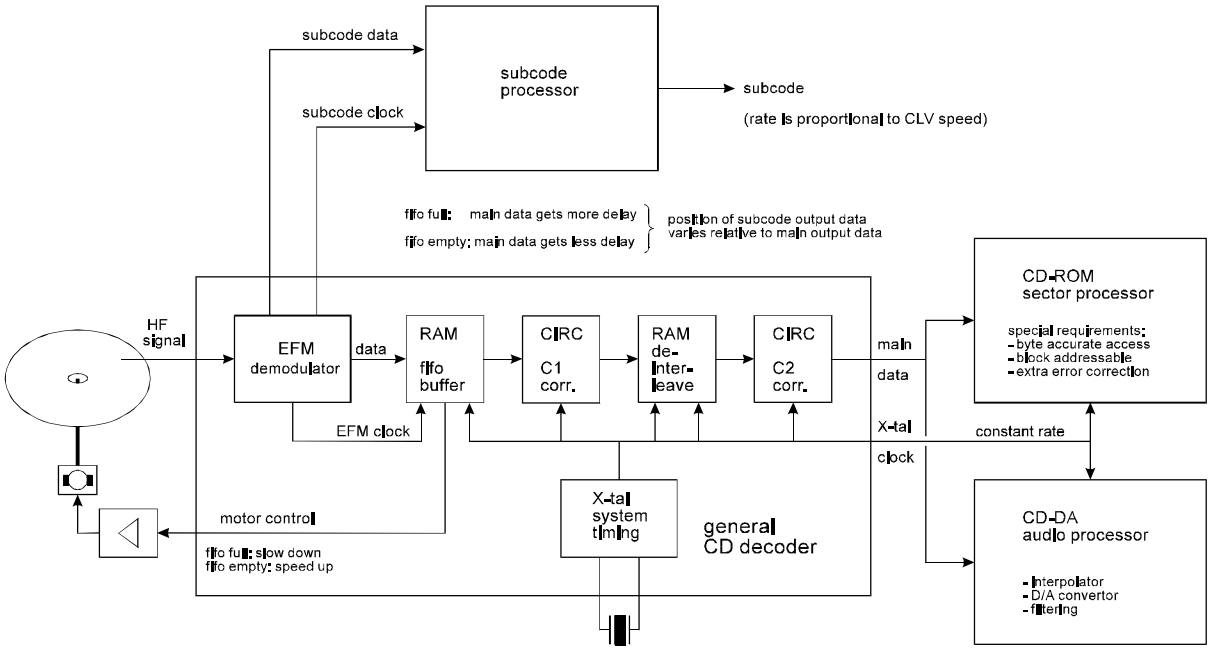

Figure 9: General block diagram of a CD player

Errors are corrected as far as possible, and the data is de-interleaved. Remaining errors can then be smoothed out by an interpolation scheme. Finally, the reconstituted PCM signal is restored to analogue form by a digital-to-analogue converter.

The effectiveness of this chain of digital signal processing is reflected in the success of CD-DA.

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2.3 Computers: CD-ROM

When CD-DA arrived, personal computers were in their infancy too. In those days, magnetic memories were, by today's standards, small in capacity and costly. The industry was crying out for a bigger, cheaper storage and interchange medium; an alternative to magnetic storage media like floppy disk and hard disk.

Meanwhile, on a CD, it was not sound underneath that polycarbonate shell; it was data. Here, in fact, was a durable, non-volatile, low-cost storage medium that could hold hundreds of megabytes. Suitably formatted, the disc became a large-capacity, easily installable, removable, portable, mailable read-only memory for computers: CD-ROM. And it retained the essential backward compatibility with CD-DA; CD-ROM drives could play CD-DA discs or tracks.

Today, an ever-growing number of CD-ROM drives is in use as computer peripherals.

The structure of CD-ROM

Sound waves are continuous in time and amplitude. They follow a pattern which, to some extent, is predictable. To reconstruct the pattern, CD-DA uses interpolation to smooth out any error bursts too long for the CIRC error correction to handle. And for track finding, addressing only really needs to be accurate enough to find the gaps between the music tracks.

Computer data, on the other hand, is intrinsically random. In general it has no pattern, and cannot be predicted. All errors have to be corrected if the data retrieved is to be usable. Furthermore, fast and bit-accurate access to individual data frames (sectors) is essential.

Sectors

CD-ROM therefore uses a 2352-byte Subcode-related frame of CD-DA as its basic unit, or Sector. To ensure data integrity and to facilitate addressing, further sync, a header, and the facility for extra error detection and correction codes are included, in addition to actual user data.

Data such as audio, video and graphics, derived from time and amplitude continuous information, does not need the extra error correction. For this type of data, CD-ROM provides a simpler Mode 2 sector, which holds 15% more data than the regular Mode 1 sector.

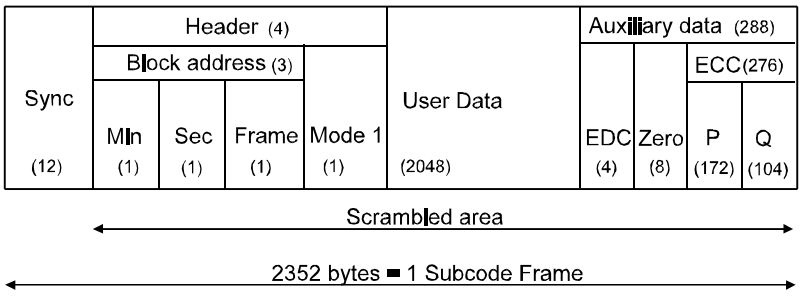

Figure 10: CD-ROM Mode 1 Sector structure

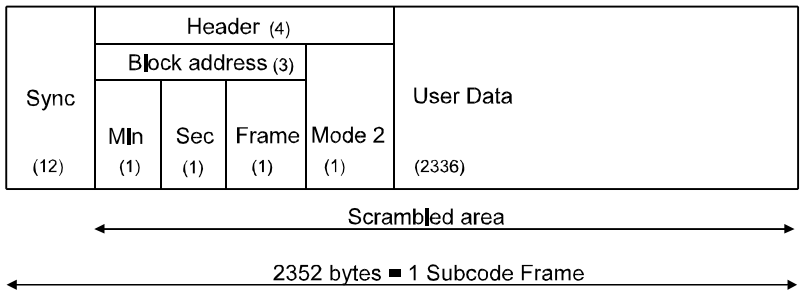

Figure 11: CD-ROM Mode 2 Sector structure

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With these provisos, CD-ROM uses the same basic format as CD-DA.

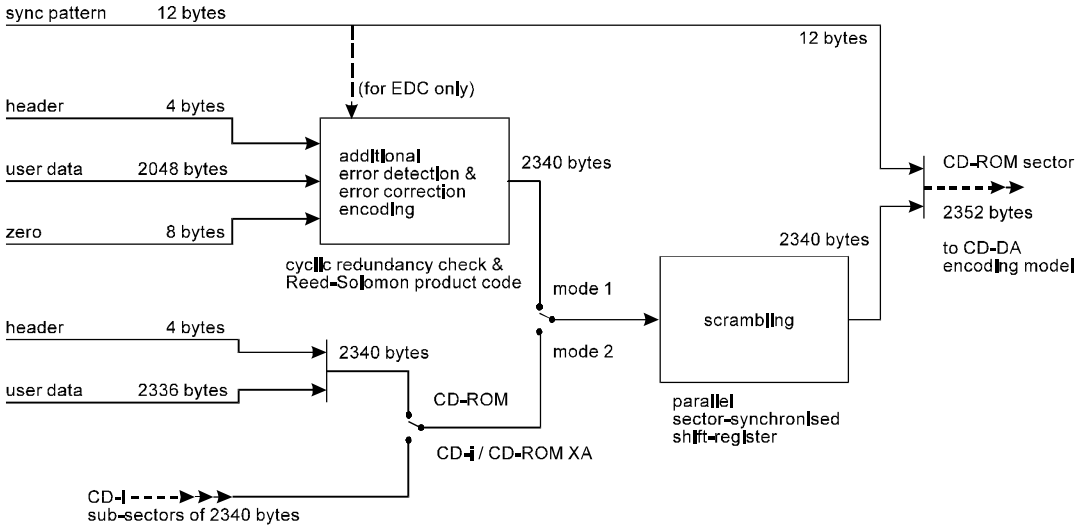

Figure 12: CD-ROM encoding model

Access

Data is accessed in two stages: the Subcode finds the region on the disc, and the required sector is then precisely identified from its address in minutes, seconds and frames, contained in the sector header. The 4-byte header also includes a mode indication byte.

As with CD-DA, the information is stored as one long spiral, as opposed to a number of concentric circles as, for example, on floppy disk. It is read at a relatively low constant linear velocity compared with floppy disc's constant angular velocity. In skipping from one point to another on the disc, the angular velocity often needs adjusting before the data can be read. Access times are therefore slower than with magnetic media. However, players that run at a double, quad or even higher speeds, are now available to shorten access times and to improve throughput rate.

File systems

The basic ability to access sectors is still not enough. Computer systems are accustomed to handling files, and different systems have always done so in different ways.
In itself, the CD-ROM System Description (Yellow Book) is open and specifies no logical file and directory structure, as different computer systems have their own particular structures. However, to reach a practical degree of compatibility between systems, some form of common structure was deemed by the industry to be necessary. This was supplied by the High Sierra Group, a working group with representation from leading companies. The results of the High Sierra Group's deliberations were eventually expressed in ISO 9660. ISO 9660 specifies a file system that is used, among others, on IBM PC-compatible systems, and has been included in later CD standards. For Unix systems, the ISO 9660 compatible Rock Ridge Interchange Protocol (RRIP) has been adopted for CD-ROM. ISO 9660 guarantees the usability of the same CD-ROM disc on different computer systems.
For Macintosh computers, the proprietary Hierarchical File System (HFS) is often used, which discs cannot be used on other computer systems.

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ISO 9660
ISO 9660 defines a hierarchical file structure, as opposed to the linear organization of tracks. A directory hierarchy allows files to be organized in a more flexible way. As starting point for access, ISO defines a disc label with a Primary Volume Descriptor (PVD), with a pre-defined location on the disc. The PVD contains the location of the root directory, and a path table that stores the addresses of all files. In this way any file can be accessed by a single seek operation. It is, of course, the static nature of the file system that makes such preprocessing possible.

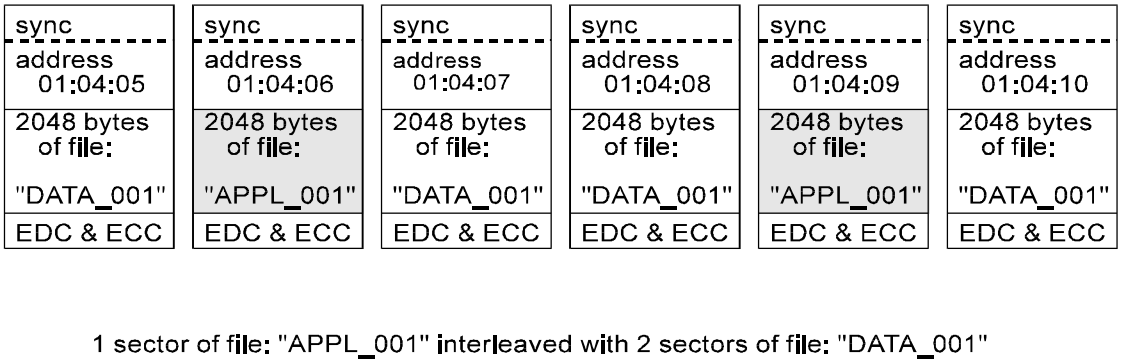

Figure 13: Example of interleaved files in Mode 1 sectors

ISO 9660 supports interleaving of files. In contrast to a track, which is a contiguous sequence of data, a file consists of sectors that need not be stored contiguously. In general, sectors belonging to one file can be positioned on the disc in groups of equal sizes, with gaps of constant size between successive groups. These gaps are available for storage of other files.

Unlike other file systems in which files may be scattered over the disc in random fashion, this regular structure not only permits random access to any one sector in a file, but also supports the implementation of what are called real-time files. These files are characterized by constraints on the rate at which they can be processed and played back. The constant rate of readout of successive interleaved sectors from disc suffices to overcome such constraints. The possibility to read a number of interleaved, real-time files simultaneously, allowing synchronized audio, video and text processing is, for example, used in CD-i.

Interleaving can also be employed to economize on disc space. If the processing rate of a real-time file is less than 75 sectors per second, it can be interleaved with other unrelated (real-time) files to fill up the disc space until a joint rate of 75 sectors per second is reached.

CD-ROM applications
CD-ROM has developed as a peripheral for a range of computer systems, each of which makes its own application arrangements. CD-ROM discs are particularly well suited to publishing large databases, offering a cost-effective alternative to on-line systems. They are also widely used for distribution of software such as technical manuals and works of reference.
In addition to the data track(s) a CD-ROM disc can also contain audio tracks. These discs are known as "mixed mode" discs. Applications of such "mixed mode" discs can be found, for instance, in games.

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2.4 Multimedia: CD-interactive (CD-i)

Not everyone feels comfortable with computers. But everyone could learn the value of a CD-ROM-like data carrier in supplying information. If only it could be made easy to use. And particularly if it could handle the forward-looking concept of multimedia.

Multimedia applications, with their intensive use of audio-visual material, are an interesting application area for CD. While CD-DA works with 1.41 Mbits of audio data per second, video is generally far more demanding with respect to storage requirements. For both audio and video, there is usually a trade-off between quantity and quality.

Thus arose CD-i. In this stand-alone concept, a development based on CD-ROM, a complete hardware and software system is specified. The disc contains the application as well as the user data, the player has a built-in computer, and the system, with its own file and directory structure and real-time operating system, can handle a broad range of specified levels of audio and video, as well as text and graphics. The way that the media are to be integrated is also defined, as well as a choice of pointing device and keyboard user interfaces. At its introduction, CD-i offered the first true multimedia environment.

The structure of CD-i

An important issue in multimedia applications is real-time operation. The audio-video material has to be played without perceptible discontinuity, and must be carefully synchronized.

As with CD-ROM, CD-i has two different sector formats, one with additional ECC (Form 1) for "error-sensitive" data and one without additional ECC (Form 2) for "capacity demanding" applications such as audio and video. These two formats use the basic CD-ROM Mode 2 sector.

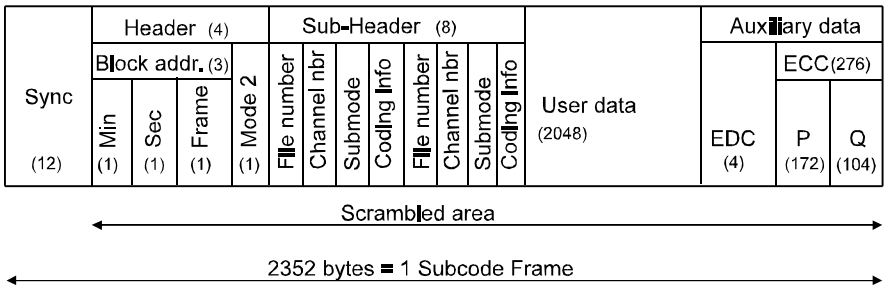

Figure 14: CD-i Form 1 Sector structure

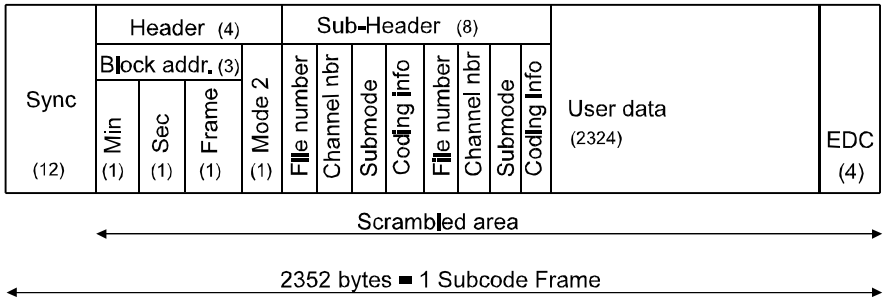

Figure 15: CD-i Form 2 Sector structure

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At the access times involved, these requirements cannot be met by random access to the relevant material on the disc. Consequently, audio-video sequences are stored on the disc in such an interleaved way that they can be played back in a single read.

Synchronization of the various types of data can be achieved by interleaving files, each containing one type of data, or by interleaving the various types of data within one file. For the latter option, CD-i uses the concept of interleaved channels. Files containing such time-critical information are known as real time files.

To process several streams of real-time information synchronously, a single real-time file may consist of channels, which can store various streams of synchronized real-time information. Channels are composed of sectors. The sectors of the channels within one file can be interleaved in arbitrary fashion. One channel, for example, could be used for video, and several other channels for the accompanying audio in various languages. Any combination of channels of one file can be chosen in real-time during play.

In order to handle lower data rates, the CD-i System Description (Green Book) allows the scattering of files along the spiral track in a regular structure. In this way, files can be read at the required speed while the laser scans the disc at a fixed speed. Scattered files can be interleaved to save disc space. See also the example in fig 18.

While compatible with the Red and Yellow Books, the Green Book lays down a disc format with five different sector types (Audio, Video, Data, Empty and Message). All these sectors are basically CD-ROM Mode 2, whereby the user data includes a Sub-header field with extra addressing information relating to file number, real-time channel number, sub-mode (for sector administration, including selection of the appropriate level of error correction and synchronization), and coding of the data type.

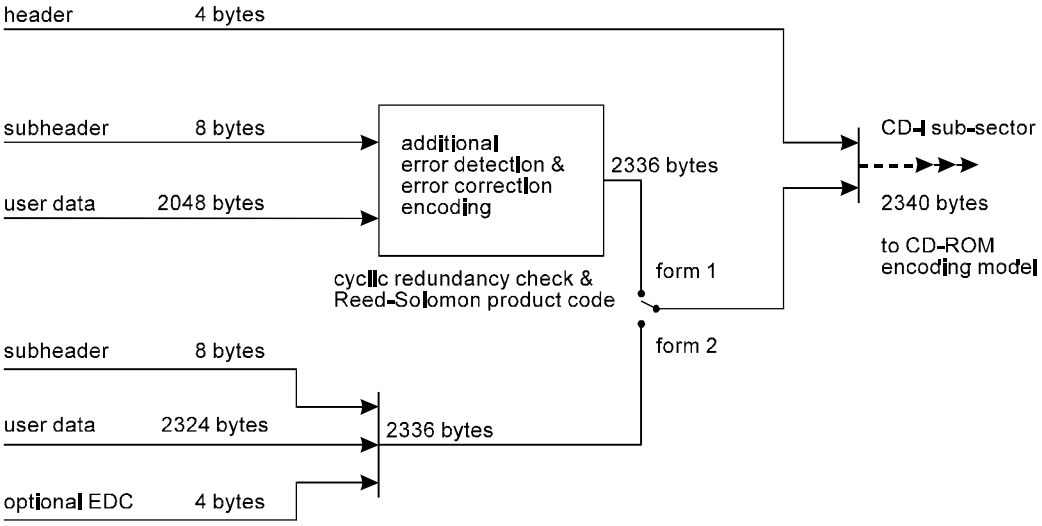

Figure 16: CD-i Encoding model

File structure

Specifications are also laid down for a file and directory structure (which are based on ISO 9660 but are not fully compatible), the audio data, real-time video data, program-related data, and the OS-9 based real-time operating system, CD-RTOS.

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Full-motion video
An extension of the CD-i standard is full-motion video, coded to the MPEG-1 (Motion Pictures Experts Group) standard as defined in ISO 11172. Only CD-i players that conform to this extension can play full-motion video.

Audio and video formats
The CD-i audio formats are the pulse code modulation (PCM) of CD-DA and adaptive differential pulse code modulation (ADPCM) at three audio quality levels. For full-motion MPEG-1 video, the accompanying audio is also encoded according to the MPEG-1 standard, for which the sampling frequency is always 44.1 kHz, while the average number of bits per stereo sample ranges from 0.36 to 5.08 bits.

In the CD-i standard, ADPCM levels A, B and C are recognized. Levels B and C are also used in CD-ROM XA. Level A uses 8 bits per sample, levels B and C use 4 bits per sample. The sampling frequencies used to measure the audio signal are 37.8 kHz for levels A and B, and 18.9 kHz for level C. This brings the bandwidth (the maximum frequency to be reproduced) to 17 and 8.5 kHz respectively.

Format	Sampling freq	Bits/sample	Bandwidth	Number of channels	Quality
CD-DA	44.1 kHz	16	20 kHz	1	Stereo
CD-i ADPCM					
Level A	37.8 kHz	8	17 kHz	2	Stereo
				4	Mono
Level B	37.8 kHz	4	17 kHz	4	Stereo
				8	Mono
Level C	18.9 kHz	4	8.5 kHz	8	Stereo
				16	Mono

Table 1: CD-i Audio quality levels

The CD-i video formats are RGB (red, green, blue), DYUV (delta luminance/chrominance), DYUV+QHY (quantized high-resolution luminance), CLUT (colour look-up table) and MPEG-1 for full-motion video. Except for the lowest CLUT with only a limited colour range, all can be used to store natural, true-colour images. The rate at which data can be read from the disc restricts the use of RGB, DYUV, or DYUV+QHY, for full-motion video, to a part of the screen only. For cartoon-like images and animations requiring just a few colours, CLUT is the usual choice. Such images can be compressed by run-length encoding of sequences of pixels of the same colour, instead of encoding each individual pixel.

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2.5 Applications

Link 1 - CD-ROM XA
If multimedia programs could be run on CD-i players, then why not on regular (personal) computers? By including a start-up program on a basically CD-ROM disc, CD-ROM XA (eXtended Architecture) makes this possible, as long as the computer system itself supports the required video and audio decoding.

In order to create a certain level of compatibility for audio and video applications, several CD-i system options have been included in the CD-ROM XA System Description. These included among others audio compression (ADPCM levels B and C), multichannel audio, some video formats, and file interleaving.
CD-ROM XA therefore also adopted the Mode 2 Form 1/2 sector format of CD-i.

CD-ROM XA drives are thus appropriate as peripherals for many types of computer, including multimedia systems as well as regular CD-ROM applications. CD-ROM XA discs do not run on CD-i players because they do not carry a CD-i application program.

Link 2 - CD-i Bridge
If a CD-i application program is added to a CD-ROM XA disc, that disc can be played on both computer systems and CD-i players. And if certain files containing information concerning disc contents and applications are also given fixed locations on the disc, it can also be played on players employing simple microcontrollers, and dedicated to particular applications.

CD-i Bridge provides this opportunity. An open standard itself, it allows specific additional details to be defined for individual applications. Photo CD and Video CD are both products of this concept. As such, they are not truly systems in themselves, but CD-i Bridge applications.

Link 3 - Multisession CD
Originally defined for CD-Write Once, the Multisession technique now also finds applications on pre-recorded media. For a CD-WO disc to be readable by standard CD-ROM drives, it needs to have a lead-in area with the Table Of Contents (TOC) in the subcode. This TOC, however, can only be generated when the disc is finished. The process of finishing the disc and writing the lead-in and lead-out area is called finalizing the CD-WO disc, and can also be performed on a partially written disc. To allow the unwritten part of the disc to be used later, the technique of "Sessions" was introduced.

A session can be seen as a "complete disc" within a CD, with its own lead-in area, program area, and lead-out area. A CD can contain more than one session and is then called a Multisession CD. On such a disc all lead-in areas, except the final one, contain a pointer to the next (possible) session. By using these pointers a Multisession compatible CD-ROM drive can access the full contents of the disc.

An example of Multisession CD is the recordable Photo CD, in which each roll of developed film is put into one session on the disc. The disc is filled up step by step as films are shot and developed, while all sessions can be read on CD-ROM and CD-i drives.

Another powerful feature of Multisession CD's is used in the Enhanced Music CD. Normal CD-audio players can only access the first session on such a disc, which is a normal audio session. The second session, a CD-ROM XA session with additional information which can be handled by CD-ROM drives in (personal) computers, is thus automatically hidden from CD-audio

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players.

Video CD
Also based on CD-i Bridge, Video CD stores digital video by using the CD-i full-motion video extension. Consequently, the pictures are encoded in conformance with the MPEG-1 standard as defined in ISO 11172. By using the compression rate of MPEG-1, 74 minutes of full-motion, full-screen video, with accompanying audio, can be recorded on a 12 cm Video CD disc.

Major applications of Video CD are linear movies, music video and Karaoke.

Video CD is defined in the Video CD specification, also known as the White Book.

Besides the ability to play on a variety of systems, including CD-i and Video CD players, and (personal) computer systems equipped with a CD-ROM drive and the appropriate hardware or software for MPEG decoding, the specification explicitly mentions the possibility of connecting a full-motion video adaptor to the digital output of a CD-DA player. In such a case, however, the player would have to be able to accept non-CD-DA discs, and to pass non-audio information to its digital output.

Note: Video CD should not be confused with the earlier CD Video, which is a hybrid of CD-DA and Laser Disc.

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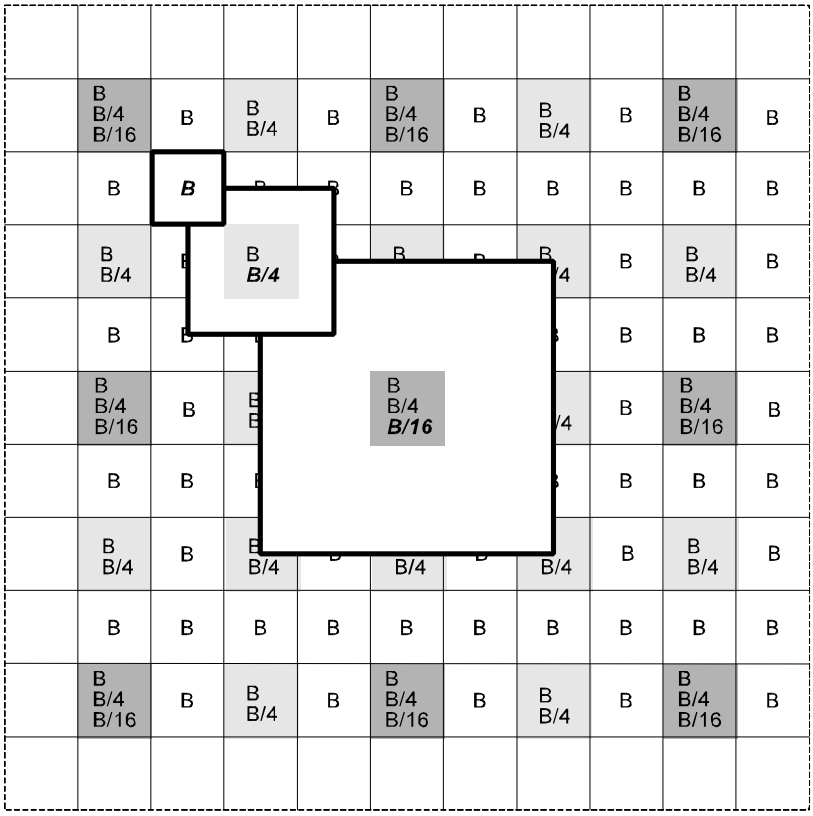
Photo CD

This CD-i Bridge based system, jointly developed by the Eastman Kodak Company and Philips, stores high-resolution photographic images fordisplay on a TV set or print-out on a hard-copy device. It provides a means of scanning photographic film, processing the images thereon, and recording them as a series of digitally-coded images of different resolutions on a Photo CD disc. These discs may be either pre-recorded or CD-Write Once (CD-WO) discs. In the latter case, images can be recorded on disc in a numberof sequential sessions. Pre-recorded discs may also contain more than one session.

The highest resolution image contains 3072 x 2048 picture elements, or pixels. However, images may be acceptable at lower resolutions, depending on the intended use. Each image is therefore stored at five resolutions, obtained by repetitively decimating the highest-resolution image by a factor of two in both horizontal and vertical directions. In increasing order of resolution, these are called: "Base/16", "Base/4", "Base", "4Base" and "16Base". The first three of these are stored directly on the disc: for many video systems these are easy to access and may have all the necessary image quality. For 4Base resolution, only the difference between an interpolated Base image and the complete 4Base image is stored, using variable-length encoding. Likewise, an interpolated 4Base image is used to store a 16Base image. On this basis, a 12 cm Photo CD disc can contain more than 100 images.



All fields constitute the Base picture,
all gray fields constitute the Base/4 picture,
the dark gray fields constitute the Base/16 picture.

Figure 17: Resolutions on Photo CD

Photo CD's are well suited for the photographic archives of both consumers and professionals. The standard also supports photo presentations with accompanying audio.

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CD-Background Music

A rather different CD-i based system, CD-Background Music is a purely audio application using CD-i ADPCM audio coding with interleaving to realize a low bitrate. Due to the ADPCM compression, only 1/8 of the CD data rate is needed. By applying 8-fold interleaving, this data rate is reached with one channel, while playing the disc at nominal speed, without any waste of capacity. Depending on the quality level required, a single disc can contain more than 20 hours of music. CD-Background Music discs only play on dedicated players.

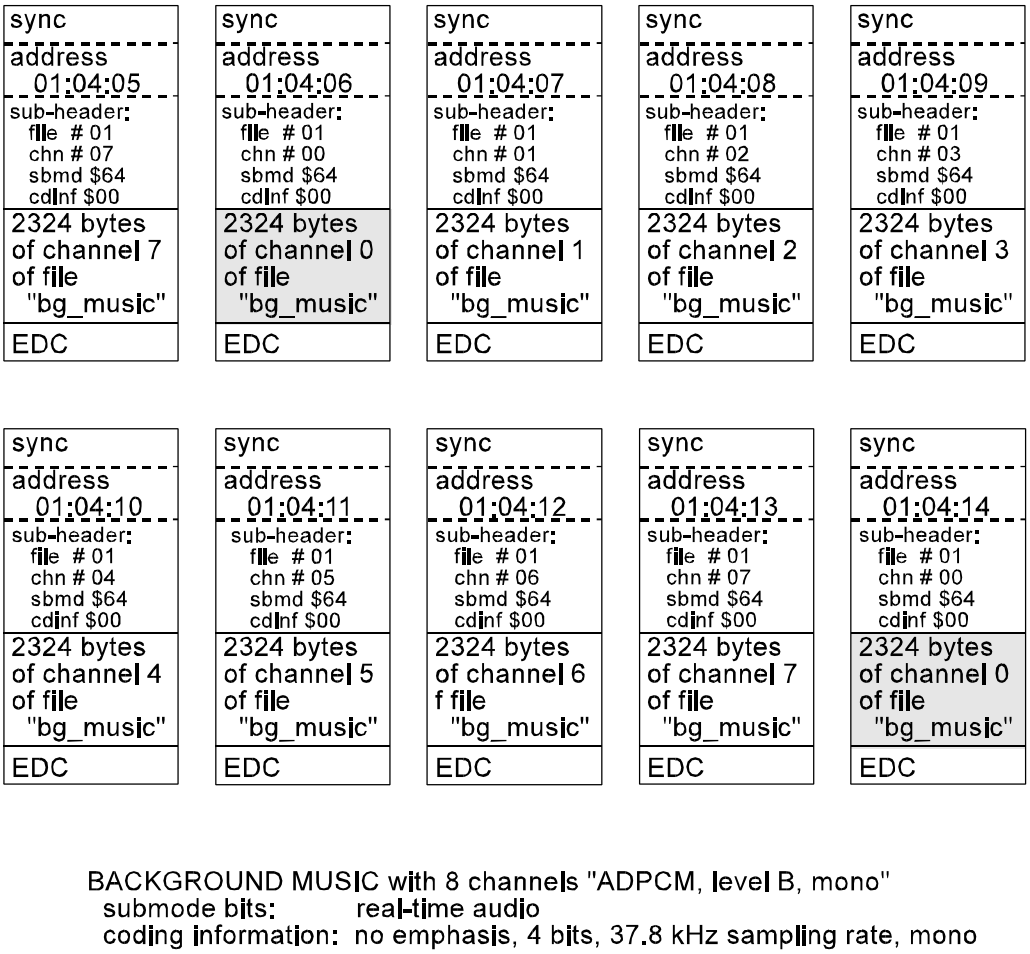
sync
address 01:04:05
sub-header: file # 01 chn # 07 sbmd $64 cdInf $00
2324 bytes of channel 7 of file "bg_music"
EDC
sync
address 01:04:06
sub-header: file # 01 chn # 00 sbmd $64 cdInf $00
2324 bytes of channel 0 of file "bg_music"
EDC
sync
address 01:04:07
sub-header: file # 01 chn # 01 sbmd $64 cdInf $00
2324 bytes of channel 1 of file "bg_music"
EDC
sync
address 01:04:08
sub-header: file # 01 chn # 02 sbmd $64 cdInf $00
2324 bytes of channel 2 of file "bg_music"
EDC
sync
address 01:04:09
sub-header: file # 01 chn # 03 sbmd $64 cdInf $00
2324 bytes of channel 3 of file "bg_music"
EDC
sync
address 01:04:10
sub-header: file # 01 chn # 04 sbmd $64 cdinf $00
2324 bytes of channel 4 of file "bg_music"
EDC
sync
address 01:04:11
sub-header: file # 01 chn # 05 sbmd $64 cdInf $00
2324 bytes of channel 5 of file "bg_music"
EDC
sync
address 01:04:12
sub-header: file # 01 chn # 06 sbmd $64 cdinf $00
2324 bytes of channel 6 f file "bg_music"
EDC
sync
address 01:04:13
sub-header: file # 01 chn # 07 sbmd $64 cdinf $00
2324 bytes of channel 7 of file "bg_music"
EDC
sync
address 01:04:14
sub-header: file # 01 chn # 00 sbmd $64 cdinf $00
2324 bytes of channel 0 of file "bg_music"
EDC
BACKGROUND MUSIC with 8 channels "ADPCM, level B, mono"
submode bits: real-time audio
coding information: no emphasis, 4 bits, 37.8 kHz sampling rate, mono

Figure 18: Example of CD-i sectors of 1 file with interleaved channels.

Enhanced Music CD

The Enhanced Music CD, also referred to as CD-Extra, is the latest branch on the ever-growing CD family tree. The disc is a Multisession CD with a CD-Audio session and a CD-ROM XA session. The CD-Audio session is in itself a "complete Compact Disc" with a lead-in, program and lead-out area. It will play on any CD-Audio player.

The CD-ROM XA session, a "second CD", contains data files related to the audio tracks in the first session with information such as the title of the album, titles of the songs, lyrics, video, artwork, graphics, etc.

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The CD-ROM XA session can be used in computer systems equipped with a CD-ROM drive, or in dedicated "Enhanced Music CD" players.
The format, as laid down in the Enhanced Music CD specification, or Blue Book, enables full-featured interactive use of the disc on multimedia computer systems, while it still behaves exactly like a CD-Audio disc on CD-Audio players.

Other derived, pre-recorded standards
Certain other read-only standards, derived in whole or part from CD, although less widely used, should perhaps also be mentioned here.

CD-Video (CD-V) is specified as an addition to the Red Book. It can store up to 5 or 6 minutes of analogue video in combination with CD-Audio (the same way as Laser Disc) together with 20 minutes of CD-Audio on a 12 cm disc. It is not to be confused with Video CD.

CD+G, CD+EG and CD-MIDI are based on CD-Audio. Through its subcode channels R..W, the CD-DA standard allows for encoding of music-related data. CD+(E)G defines the way in which simple text and (extended) graphics can be recorded for display on either a player display or a TV set. CD-MIDI similarly defines the way of recording data conforming to the Musical Instrument Digital Interface.

2.6 CD-Recordable systems
All the systems so far described are pre-recorded systems, and lack the facility of recording as enjoyed by tape systems. CD-Recordable systems address this deficiency.

CD-MO
The first version of CD-Recordable, CD-MO, used a magneto-optical recording technology. MO technology is not compatible with the basic optical parameters, like reflectivity, of CD. As a result, it has not gained wide acceptance. It should be noted, however, that the Mini Disc system is based on CD-MO-like technology.

CD-WO
CD-Write Once (CD-WO) has the advantage of full compatibility with all pre-recorded CD systems. It also introduces the additional concept of multisession (hybrid) discs.

The key to CD-WO is an organic dye coating (the photo-absorption layer) applied over a substrate containing a wobbled tracking groove. The wobble frequency of the groove is FM modulated with timecode information. The average wobble frequency is used to control the turntable motor speed, while the timecode information is used to position recordings on the disc.

The organic dye coating, on its turn, is covered with a reflective layer. The coating is initially transparent, and for recording it is heated by a laser beam. When the intensity of the laser spot passes a certain threshold, a bump appears in the layer. This is an irreversible process which drastically alters the optical characteristics. Using this technique, a pit (or rather, bump) pattern is written in the tracking groove by a relatively high-power laser in a dedicated recorder. The laser power required for recording is typically an order higher than the 0.5 mW laser power used for reading.

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Sessions
CD-WO sessions can be recorded at different times, and even on different recorders. Each session has its own lead-in, programme and lead-out area, and can itself be recorded in parts over any period of time. One session must be finalised before another can be begun, and every single sessions on a disc must conform to the CD-DA, CD-ROM, CD-ROM XA or CD-i standard. The format of each session is indicated in the Subcode in the lead-in area of that particular session.

The first session on a CD-WO disc can be played by a regular player of the appropriate type, but a multisession player is needed to play all the sessions.

CD-WO applications
CD-WO offers speedy, convenient, large-capacity long-term storage at a relatively very low cost per megabyte. It can be used for do-it-yourself, one-off applications such as application prototyping and mastering, data storage and retrieval, low-volume software distribution, in-house publishing, photo file archiving, and simple presentations.

CD-Erasable (CD-E)
1995 saw the announcement of the CD-Erasable (CD-E) system description. CD-E may be seen as a logical extension of the CD-Recordable series of systems, based on the same pre-grooved substrate as CD-WO with just another type of recording layer. CD-E drives will be able to write, read and re-write CD-E discs, as well as writing and reading CD-WO discs and reading all CD-ROM discs. While CD-WO finds applications in small office environments, such as large file exchange and archiving, CD-E fulfills the role of back-up medium in business-critical applications and personal storage, as if it were a huge floppy disk. With only a minor modification in electronics, which all CD-ROM drive manufacturers can easily implement, future CD-ROM drives will also be able to read CD-E discs .

How CD-E recordings are made and erased
An erasable CD technology must, of necessity, be in harmony with the existing CD systems. Philips therefore turned away from incompatible Magneto-Optics, and persevered with phase change technology, by itself quite challenging in compatibility terms. Phase, in this context, refers to the physical aggregation state of the material used for the recording layer of the disc. There are two possible phases, with quite different optical properties. A low-reflectance domain of amorphous, or patternless, phase (equivalent to a CD pit) is produced when a laser heats the recording material rapidly above its melting point of 500-700°C. Cooling very quickly, the amorphous domain "freezes". On the other hand, if the recording material is heated to a rather lower temperature for a somewhat longer time, a higher-reflectance domain of polycrystalline phase is formed, equivalent to a CD land.

The life of CD-E discs under this heat treatment is at present about 1000 write/erase cycles. Although this is a lot shorter than the life of MO discs, it can be expected to increase, and is in any case certainly adequate for the foreseen applications.

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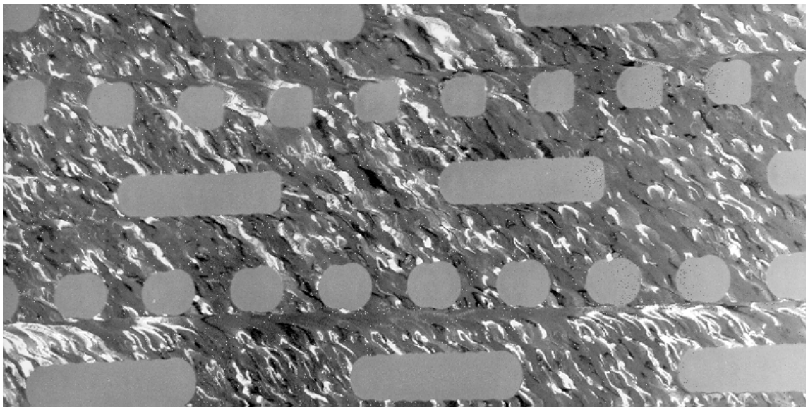

Figure 19: "Pit" structure of CD-E disc

Readout considerations
Phase change tracks are read in the same way as regular CD tracks. The readout mechanism does no more than detect the transitions between low and high reflectivity, and measure the length of the periods between those transitions. Although the reflectance is lower than for regular CD's, the relative proportions of light reflected from the amorphous and polycrystalline phases remains the same.

A question of gain therefore arises. CD's reflectance specifications - 70% minimum for lands, 28% maximum for pits - allowed the relatively insensitive photodiodes of the early eighties to read the signal pattern reliably. But with these specifications, the development of a recording material is a practically impossible task; if 70% of the light is reflected, only 30% at most remains to change the phase. Nowadays, these levels are not necessary: the photodiodes of today are able to detect much lower reflectance differences. All that is needed is the correct reflectance ratio and adequate amplification.

A realistic erasable system has to work on reflectivities of about one-third of the original CD figure. Once this constraint was accepted and written into the specification, phase-change CD-E became a perfectly practical and reliable proposition. The new CD-R/E drives (CD-WO drives with the CD-E extension) will write and re-write the CD-E discs - as well as writing CD-WO discs. And future CD-ROM drives, fitted with automatic gain control, will be able to read them.

The recording material for CD-E consists of a layer of silver, indium, antimony and tellurium. The polycrystalline phase reflects about 20% of the light, the amorphous phase only 8%. That meets the requirement for a minimum modulation of 60%, and allows for writing by a laser of 10-15 mW.

CD-E thus conforms to the original CD specification except in one small respect. The discs have equal dimensions and store the same quantity of data. The drives embody a small modification, but in other respects are identical. Once they are in quantity production, CD-R/E drives need not be more expensive than their CD-WO predecessors.

CD-E applications
CD-E is not intended to supersede CD-WO, but rather to do the work that CD-WO cannot conveniently do, such as editing applications. All future Philips CD-R/E drives will be designed to work with both types of disc.

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2.7 The relationships in the CD Family

The way in which the members of the CD Family are related is shown in 3-dimensional form in fig 20.

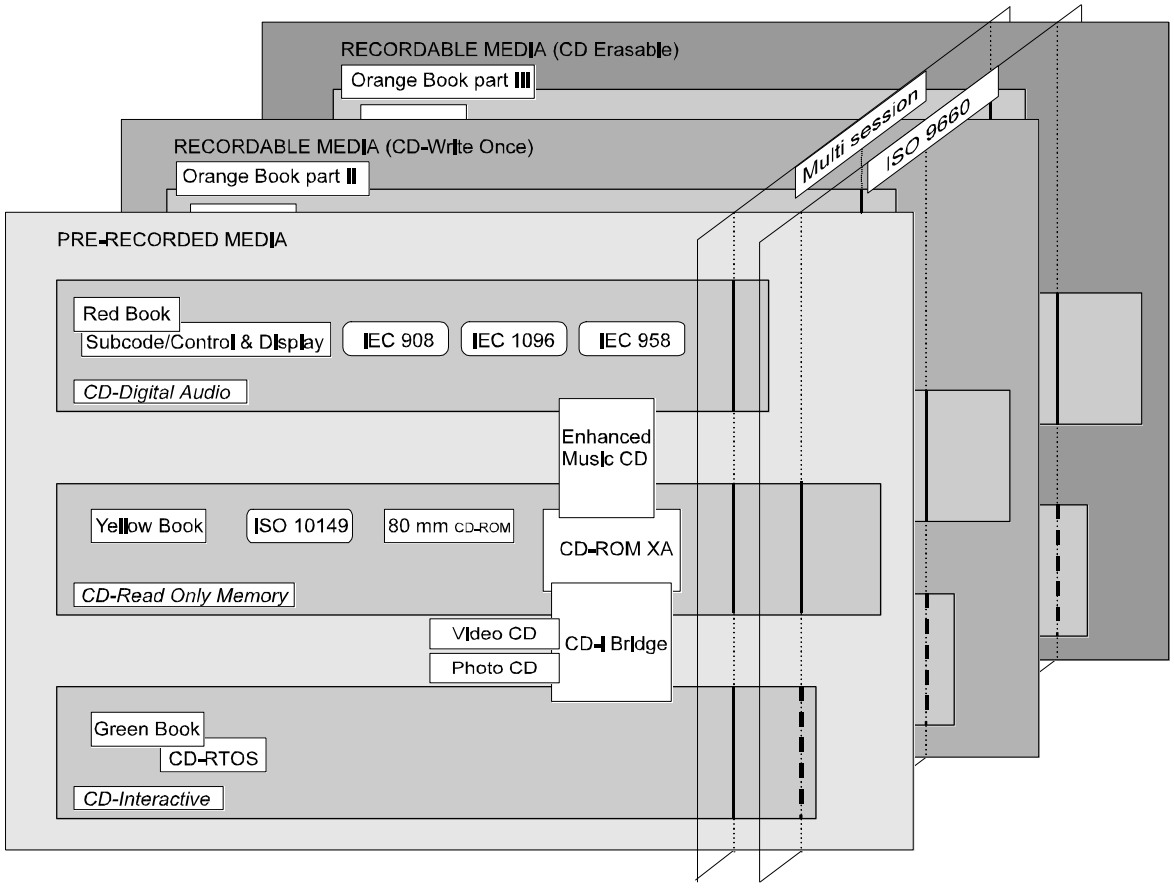

Figure 20: Interrelation of CD Standards.

Each of the three different planes represents one of the CD Media fields: Prerecorded, Write Once and Erasable. In each field, the same basic CD systems occur: CD-DA (Red Book), CD-ROM (Yellow Book) with CD-ROM XA, and CD-i (Green Book).

The interrelationships between these main systems are depicted by the standards which span them: Enhanced Music CD (Blue Book), and CD-i Bridge, with its present applications to Video CD (White Book) and Photo CD.

In addition, the three fields are all intersected by two planes of functional linkage: multisession and ISO 9660. The Multisession CD standard applies in general to systems in all three fields. ISO 9660 also applies to all three fields, but only with respect to the CD-ROM branch and, to a limited extent, to CD-i (as indicated by the broken line).

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3 A ROAD MAP

Computers and consumer electronics have been converging for years now, a tendency accelerated by the development of the CD optical disc family, which opened the way to the recent explosive growth of multimedia systems. As the road map of Fig.21 shows, digital video developed along a separate path from CD-DA, and is now in the market in the form of CD-I Video CD, and MPEG-1 compression under ISO 9660.

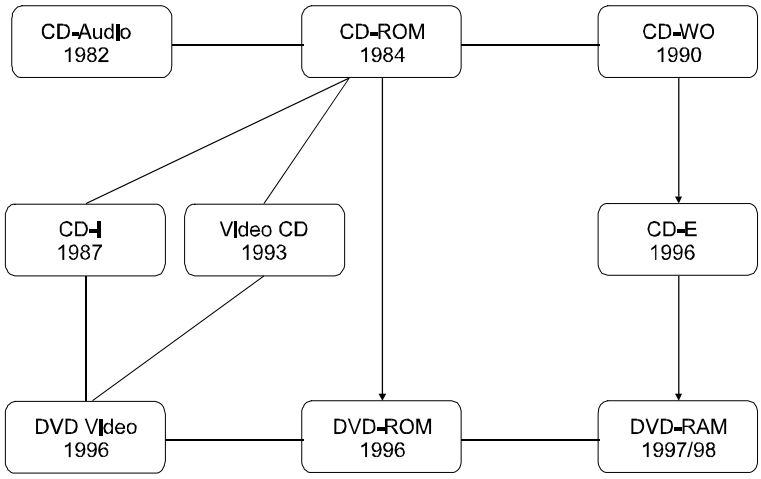

Figure 21: A roadmap towards future developments

As this convergence continues, the need is growing in the film industry for a new high-capacity video disc, and in the computer industry for an equally high-capacity ROM disc. Both sets of requirements are likely to be met by a new high-density disc, which is in essence a ROM equally fitted for digital video and computer applications. This is portrayed by the highway at the bottom of the map.
For prerecorded media, the reduced pit and track dimensions and the improved format structure of high density discs will mean greatly increased data capacity. This will lead to longer video playing times, allowing practically all films to be accommodated on single-disc albums, and an equal potential for far more sophisticated software programs.

The write-once and erasable media will also benefit from the improved structure of the high-density format. For data retrieval, the recommended volume and file structure will be in accordance with the new "UDF" standard (released by "OSTA"), leading to better compatibility with future recordable systems.

High-density Erasable could also have the capability to record digital (MPEG-1 and MPEG-2) video, subject of course to satisfactory copying constraints. And there are other ways of making video recordings than copying; from camcorders, for instance. Future PCs, with high-density WO/E drives, will be powerful tools for re-editing digital video material from a variety of sources. Fast and easy random access to recordings on disc (as opposed to tape), and virtually unlimited archival life, are solid benefits that will be felt by both consumers and professionals in the computer and video sectors.

The technologies developed under the auspices of Compact Disc have played, and will continue to play, a major role in the phenomenon of multimedia consumer electronics.

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Glossary of terms

Access time
The time required by a CD-ROM drive to read the data requested from the CD-ROM disc and send it back to the computer.

ADPCM
Adaptive Differential Pulse Code Modulation is a method of compressed audio data storage in which it is not the value of the signal which is stored, but the difference from the previous sample (or measurement). This means that only 8 or 4 bits per sample are used, rather than the normal 16 bits.
In the CD-i standards, the levels A, B and C are recognized. Levels B and C are also used in CD-ROM XA. Level A uses 8 bits per sample, levels B and C use 4 bits per sample. The sampling frequencies used to measure the audio signal are 37.8 kHz for levels A and B, respectively 18.9 kHz for level C. This brings the bandwidth (the maximum frequency to be reproduced) to 17 and 8.5 kHz.
For normal linear PCM the number of bits is 16, the sampling frequency is 44.1 kHz and the audio bandwidth is 20 kHz. Using ADPCM, a maximum 16-fold reduction in storage requirement relative to linear PCM can be achieved (Level C, mono).

ASCII
American Standard Code for Information Interchange; a coding scheme which represents characters in an 8-bit binary format. Almost every language uses the same coding for the first 128 symbols in this table. Different tables are in use for ASCII number 128 to 255.

Backup
A reserve copy of information so that, in case of emergency, the old situation can be restored.

Bit
The smallest unit of information within computer systems. Contraction of "binary" and "digit". A binary digit has the value "0" or "1".

BER
Bit Error Rate; expressed as the average ratio of the number of erroneous bits and the total number of processed bits. For CD-ROM the figure is typically about 10^{-15}.

BLER
Block Error Rate; expressed as the number of blocks (= EFM frames) with at least 1 error, against the total number of blocks processed.

Block
In CD-ROM technology the data is stored on the CD-ROM in blocks, sometimes called sectors or frames, of 2 KByte (2048 Bytes). Apart from the user-data, extra information is added (see: Mode 1/2, Form 1/2).

Byte
A symbol or character, consisting of 8 bits.

CAV
Constant Angular Velocity, a fixed number of disc revolutions per second.

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CD-DA or CD-Audio
Compact Disc Digital Audio, the "normal" audio CD. The standard is defined by Philips and Sony in the Red Book.

CD-i Bridge disc
A special type of CD-ROM XA disc with a CD-i application program. By using the CD-i Bridge disc concept, the discs can be played on a variety of players, such as CD-i, CD-ROM XA, etc. Examples are Photo CD and Video CD.

CD-i
Compact Disc Interactive; a system for presenting information (text, images and video) on a television screen. The standard is defined by Philips and Sony in the Green Book.

CD-ROM
Compact Disc Read Only Memory; a storage medium which can only be read, based on CD-Audio technology.
Maximum capacity in Mode 1:
for 74 minutes: 681,984,000 Bytes = 650 MByte
for 63 minutes: 580,608,000 Bytes = 553 MByte
where 1 minute = 60 seconds;
1 second = 75 frames;
1 frame = 2048 Bytes.
The standard is defined by Philips and Sony in the Yellow Book.

CD-ROM XA
XA stands for eXtended Architecture and is a standard for CD-ROM in which a number of options from CD-i have been added. These include audio compression (ADPCM), multi-channel audio (max. 16), file interleaving and image compression.
A CD-ROM XA disc is a Mode 2 disc, in which the data is located in Form 1 (2048 user Bytes/sector) or Form 2 (2324 user Bytes/sector) sectors.

CLV
Constant Linear Velocity, a condition in which a uniform relative velocity is maintained between the disc and the pickup.

Data Compression
A technique in which as much redundant information as possible is removed from the data, e.g. a repetitive sequence can be stored as the sequence value and the number of repetitions.

Data Conversion
Method of transforming data from one electronic storage format into another format, e.g. converting a word processor text into ordinary ASCII code.

Directory
A file that contains information (name and location) about the files on a disk. Used with almost every storage medium (floppy, hard disk, CD-ROM).

ECC
Error Correction Code; redundant information used to correct erroneous bytes.

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ECMA
European Computer Manufacturers Association. ECMA has close working relations with European and international standardization bodies like IEC and ISO.

EDC
Error Detection Code; a checksum over the Bytes in a sector or frame. This enables decoders to conclude immediately that an error has occurred during the reading of the information. With the use of ECC, errors of this kind can be corrected to a certain extent.
EDCs are applied for instance in the CD Subcode and in the CD-ROM data sectors.

EFM
Eight to fourteen modulation. A method of modulation of 8 bits into sequences of 14 bits. These groups of 14 bits are "linked together" by 3 merging bits.

Floppy disk
Removable magnetic medium in a synthetic jacket. Information can be stored on it, using a read/write head. The information is rewritable.

FMV
Full motion (full screen) video.

Form 1
Used in CD-i and CD-ROM XA. Division of a Mode 2 sector into Sync (12 Bytes), Header (4 Bytes), Subheader (8 Bytes), User data (2048 Bytes), EDC (4 Bytes) and ECC (276 Bytes). This layout is used for normal data files (including Photo CD).

Form 2
Used in CD-i and CD-ROM XA. Division of a Mode 2 sector into Sync (12 Bytes), Header (4 Bytes), Subheader (8 Bytes), User data area (2324 Bytes) and 4 Bytes EDC (or reserved). This layout is used for files where error correction is less important and the highest possible data rate is needed, such as (compressed) audio or moving images.

GB
GigaByte: 1024 MB.

Hard disk
A permanent (non-removable) storage medium for computer data, based on a rotating disc with a magnetically sensitive layer. Information can be written on this and read again, using a read/write head. The information stored is rewritable.

HFS
Hierarchical File System, used by Apple. Used for floppy and hard disks and for CD-ROM.

High Sierra
The predecessor of the ISO 9660 standard; published by the CD-ROM Ad Hoc Advisory Committee, also known as the High Sierra Group, on May 28th 1986. Use of this "standard" is no longer recommended. ISO 9660 is to be preferred.

IEC
International Electrotechnical Commission. See also ISO.

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Index
A separate list of words or keys, sorted alphabetically or numerically, along with a reference to their location in the text of a database.

Injection Moulding
The process in which polycarbonate is forced under pressure against the stamper to produce a CD.

Interactive Media
Media in which the user is required/expected to take action to find information, or to be provided with information.

Interface
Point of contact or border surface between two systems. These can be items of equipment e.g. SCSI interface between computer and CD-ROM player or software modules e.g. user interface.

ISO
International Standardization Organization. The ISO together with the IEC forms a system for worldwide standardization as a whole.

IT
Information Technology.

JPEG
A compression algorithm defined by the Joint Photographic Experts Group for continuous tone images (colour pictures). Permitting loss of information non-essential for human observation, compression rates of 10-30:1 can be achieved. "Loss-less" compression cannot currently go beyond 8:1.

Karaoke
Japanese word meaning "empty orchestra". A form of entertainment where guests e.g. in a Karaoke bar can take a microphone and start singing to the musical backing.

KB
KiloByte: 1024 Bytes.

LaserVision
An analog optical video disc system.

Mastering
The process in which a Glass Master is produced, needed to make Stampers, which are in turn used for the replication of CDs. The glass master is coated with photosensitive lacquer which is illuminated on a Laser Beam Recorder (LBR). The data for mastering comes from a premaster tape or from a CD-WO disc.

MB
MegaByte: 1024 KB.

Mode 1
A CD-ROM sector with Sync (12 Bytes), Header (4 Bytes), User Data (2048 Bytes), EDC (4 Bytes), Zero (8 Bytes) and ECC (276 Bytes).

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Mode 2
A CD-ROM sector with Sync (12 Bytes), Header (4 Bytes), and User Data (2336 Bytes). For CD-i and CD-ROM XA, 2 specific formats are specified in Mode 2: Form 1 and Form 2.

MPC
A definition for the Multimedia PC including CD-ROM drive as put forward by Microsoft. The MPC logo tells the user that an MPC application will work on an MPC computer.

MPEG
A norm for the compression of motion video, developed and defined by the Motion Picture Experts Group. This has become the ISO standard and is used in CD-i and Video-CD players. The algorithm used (Discrete Cosine Transform), makes an extremely high rate of compression (200:1) possible.

NA
Numerical Aperture; a combined measure for the diameter and the focal distance of an optical lens.

OSTA
Optical Storage Technology Association.

PCM
Pulse Code Modulation; digital encoding of the amplitude of a signal. The number of bits to express the amplitude value is dependent on the required signal to noise (S/N) ratio. For CD-Audio this is 16 bits, resulting in S/N > 96 dB.
The frequency with which the amplitude has to be measured (the sample rate) is dependent on the required bandwidth. For CD-Audio the sampling rate is 44.1 kHz, resulting in a bandwidth of 20 kHz. PCM does not use compression.

Premaster tape
The magnetic tape used in CD-Audio and CD-ROM replication companies to produce the CD master with which the CD's themselves are pressed.

Replication
The production of identical copies of a Compact Disc from a stamper.

Retrieval
Term for calling up of information in databases. The retrieval usually takes place on the basis of indexes.

Scrambling
Randomizing data by adding a pre-defined pseudo-random bitstream to the data stream Scrambling is applied to prevent the occurrence of fixed, repetitive data patterns.

Stamper
The metal "form" used to press a CD in the injection moulding process.

Subcode
Information (track, time, text, graphical or MIDI) stored together with audio on a CD. The Subcode is spread across 8 channels (PQRSTUVW). P and Q contain the track and time information shown on the display of an audio CD player.

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TOC
Table Of Contents: a list in the subcode in the lead-in area of the disc, containing the starting addresses of the tracks in the program area.

Transfer rate
The speed with which information can be transferred. Usually expressed in terms of KiloBytes per second. A standard CD-ROM drive is rated at 150 KB/sec. A double speed player can deliver 300 KB/sec.

UDF
Universal Disc Format, a proposed file format as follow-up for ISO 9660.

Volume
The CD-ROM term for a CD-ROM disc. In the case of extremely large databases it is possible to define a "volume set", consisting of a number of CD-ROM discs which together form a whole.

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References

- CD-DA: Compact Disc Digital Audio,
  specified in the System Description Compact Disc Digital Audio ("Red Book"),
  N.V. Philips and Sony Corporation.

- CD-ROM: Compact Disc Read Only Memory,
  specified in the System Description Compact Disc Read Only Memory ("Yellow Book"),
  N.V. Philips and Sony Corporation.

- CD-i: Compact Disc Interactive,
  specified in the CD-i Full Functional Specification ("Green Book"),
  N.V. Philips and Sony Corporation.

- CD-ROM XA: Compact Disc Read Only Memory eXtended Architecture,
  specified in the System Description CD-ROM XA,
  N.V. Philips and Sony Corporation.

- CD-i Bridge: Compact Disc Interactive Bridge,
  specified in the CD-i Bridge Specification,
  N.V. Philips and Sony Corporation.

- Video CD: Video Compact Disc,
  specified in the Video CD Specification,
  N.V. Philips, JVC, Sony Corporation and Matsushita.

- Multisession CD: Multisession Compact Disc,
  specified in the Multisession CD Specification,
  N.V. Philips and Sony Corporation.

- Enhanced Music CD: Enhanced Music Compact Disc,
  specified in the Enhanced Music CD Specification,
  N.V. Philips, Sony Corporation and Microsoft Corporation.

- CD-WO: Compact Disc Write Once,
  specified in the System Description Recordable Compact Disc Systems,
  Part II: CD-WO ("Orange Book Part II"),
  N.V. Philips and Sony Corporation.

- CD-E: Compact Disc Erasable,
  specified in the System Description Recordable Compact Disc Systems,
  Part III: CD-E ("Orange Book Part III"),
  N.V. Philips and Sony Corporation.

- Photo CD: Photo Compact Disc,
  specified in the System Description Photo CD,
  N.V. Philips and Eastman Kodak Company.

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- MPEG-1 standard:
  Information technology - Coding of moving pictures and associated audio for digital storage media at up to about 1,5 Mbit/s
  Part 1: Systems ISO/IEC11172-1:1993(E)
  Part 2: Video ISO/IEC11172-2:1993(E)
  Part 3: Audio ISO/IEC11172-3:1993(E)

- ISO 9660:
  Information processing - volume and file structure of CD-ROM for information interchange.

- ISO 10149:
  Information Technology - Data interchange on read-only 120 mm optical data disks (CD-ROM).

- IEC 908:
  Compact disc digital audio system.

- IEC 958:
  Digital Audio Interface

- IEC 1096:
  Methods of measuring the characteristics of reproducing equipment of digital audio Compact Discs.

- DAG 320, DAG 321, DAG 322:
  Specification of the 3/4-inch cassette type CD-master tape, N.V. Philips and Sony Corporation.

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Authors biographies

Boudewijn van Dijk After his graduation in electronics, Boudewijn joined the Philips Research Laboratories in 1970. For a number of years he worked on broadcast radio and cable television systems.
In 1979 he joined the Philips business unit ODM (Optical Disc Mastering). At ODM he was responsible for the development of the Compact Disc signal processing electronics used in CD Mastering equipment. In 1988 he became product manager responsible for CD pre-mastering and mastering systems. After the merge of ODM and OD&ME into a new independent company ODME (Optical Disc Manufacturing Equipment) in 1991, he also became responsible for the marketing issues of CD test-equipment and the Automatic Mastering System.
In August 1995 he joined Philips Consumer Electronics as manager, standards and licensing. Boudewijn is co-author of several publications including Corporate CD-ROM Publishing, High density CD an industrial approach and Dataconversion, a premastering activity.

Jaap Nijboer received his electrical engineering degree in Electronics from the University of Technology, Delft, The Netherlands, in 1974. Immediately after finishing his studies, he joined the Philips Portable Radio & Cassette-recorder design group in Eindhoven, working on predevelopment and IC design activities.
From 1978, he was involved in Compact Disc system research and development, in the Audio Division of the main industry group Consumer Electronics of Philips.
In 1987 he joined the business unit ODM (Optical Disc Mastering) of Philips, which department, in 1991, merged with OD&ME in Veldhoven, and formed the independent company ODME (Optical Disc Manufacturing Equipment). With ODM / ODME he was involved in all aspects of CD and LD pre-mastering, mastering, replication & quality control.
Since June 1995 he has been with Philips Media System B.V. as Standardization Officer for CD-related systems and products.

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